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Frequency / power standard for calibration

Measuring instruments such as frequency counters or wattmeters are among the standard tools of many active radio amateurs. This equipment is often required to monitor ones own radio station or as an aid in circuit design and assembly of RF equipment. To be able to test that this equipment is functioning correctly and to calibrate it, a frequency / power standard is an important tool.

The following article describes the basic considerations for the circuit concept and assembly of such a standard.

1. Considerations regarding circuit design

The aim of this article is to create a frequency / power standard for calibrating simple frequency counters and wattmeters (mW meters) with a diode detector or a bolometer head. Important considerations for this concept are, manageable implementation cost and technical comprehensibility (not only for experienced technicians).

In order to satisfy the requirements of the shortwave, ultra shortwave and UHF/ VHF users at the same time, a compromise must be found with regard to the output frequency. The range around 50MHz is suitable here for both the shortwave amateur and the GHz components usually designed for broadband use. For example, commercial diode detectors may well be specified for up to 18GHz (or beyond!), but can not be used at low frequencies, i.e. <=10MHz.

On the other hand detectors developed, e.g. as do-it yourself projects, supply usable results only up to a few 100MHz. This is also true for resistance bridges in bolometer heads.

From the description, “frequency / power standard for calibration purposes”, in addition to the precise frequency a precisely defined output level must also be available. Normal mW meters are designed for up to 100mW (+20dBm). This output should also be used for this project. Lower power levels can easily be created without any problem by means of a downstream attenuator. An attenuator that can be switched in 1dB steps is an interesting option [1].

Oven stabilised oscillators (OCXOs) are practically tailor-made for generating a high precision frequency output. The characteristics of such an OCXO are far beyond everything the radio amateur is used to from the measurement equipment available to him or her. For example, the short-term frequency stability of an HP10544A is specified at 1 x 10^{-11}/1s (1Hz at 100GHz), with a long-term sta-

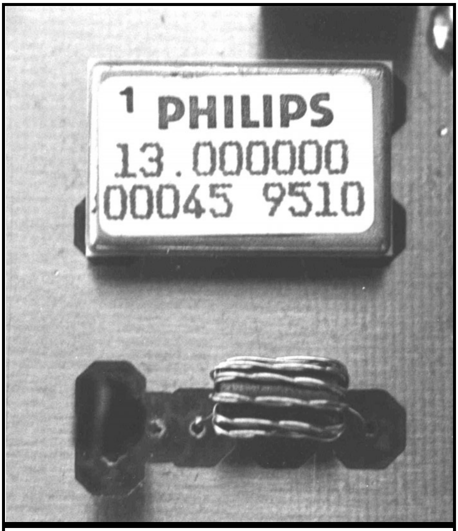

Fig 1: Picture of the TCXO in a 15mm x 25mm housing.

bility of <5 x 10^{-10}/day. Normal frequency counters, with a crystal as the internal oscillator for the gate time control offer only 10^{-6} Hz/1s here (1Hz at 1MHz). The short-term stability, and thus the accuracy of measurement of the frequency counter, is thus worse by a factor of 100,000!

Of course, the price of such oscillators is a deterrent to many people. Even in flea markets, you have to pay more than 100 Euros for used OCXOs of this type. For new oscillators, the price would certainly reach four figures.

Alternatively, temperature compensated oscillators (TCXOs) are also available. It is true that their frequency stability is lower than that of a good OCXO, but, with a short-term stability of approximately 1 x 10^{-8} Hz/1s (1Hz at 100MHz), is still better by two powers of ten than what many of us can reckon with today.

If a higher frequency precision is required, then the link to a high quality frequency standard can be made without any problem, using a PLL control circuit.

A controlled amplifier must be used in order to obtain the defined power level of 100mW. The precision of this power level is only dependent on the reference used.

One consideration is the thermal behaviour of the control circuit. However, because components are available at favourable prices, this problem is much easier to solve than the one relating to frequency stabilisation.

Starting from the assumption that such a frequency / power standard is usually used at room temperature, this calibration aid can be created at an acceptable price.

2. Approach to a solution

Highly stable oscillators are currently available based on GSM technology but an interesting product, manufactured by Philips, is available at a favourable price. The TCXO (Fig. 1) oscillates at 13.0000MHz. Various measurements have given a short-term stability of ±2 x 10^{-8} Hz/1s for the frequency.

The precise oscillation frequency can be finely adjusted using a control input, by means of a tuning voltage (0.5V). In Fig. 2, the frequency response is plotted against the voltage feed.

The oscillator frequency of 13MHz is, at first glance, unusual. If the frequency is quadrupled to 52MHz, the nominal frequency for the frequency / power standard is generated. The TCXO frequency divided by 13 gives 1MHz. The oscillator can be easily synchronised with a high quality frequency standard, for example, 10MHz by means of a PLL.

The frequency of 52.0000MHz generated in this way can achieve the defined output level of 100mW. The amplifier must be able to deliver this output reliably and should still have a few dB in reserve. A small part of the output signal is rectified and fed back to a PIN diode

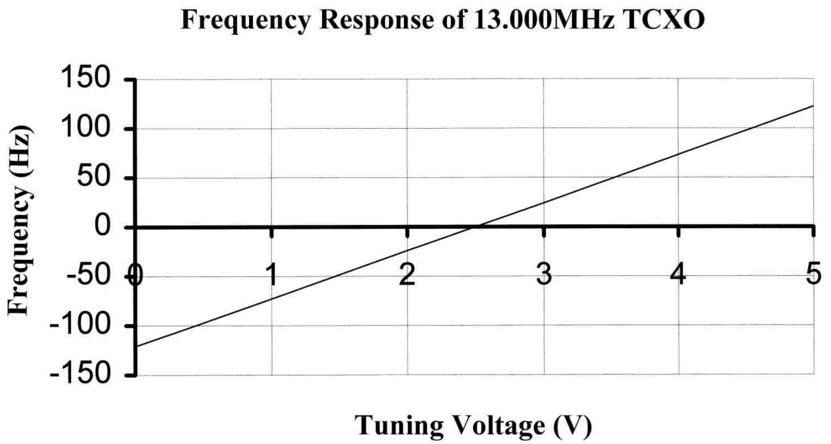

Fig 2: Frequency change of the TXCO with change of tuning voltage.

regulator connected in series to the amplifier.

3. The TCXO assembly

The core of the TCXO assembly is the temperature compensated quartz oscillator (IC1) for 13MHz. At an operating voltage of just 6V, this TCXO supplies an extremely stable output frequency with a level of approximately 0.3Vss.

The short-term frequency stability of the oscillator is better than $\pm 2 \times 10^{-8}$ Hz/1s. The precise frequency is finely adjusted with the R5 trimmer (2 kΩ). The possible tuning range is shown in Fig. 2.

Only a small part of this wide tuning range (±3 Hz) is used for this application. The resistance combination R2/R3 is used to pre-set the frequency. The process to determine the necessary resistance values, depending on the power supply and, naturally, the specimen mean variations of the TCXO module, is described in detail in the following instructions for assembly and putting into operation.

The TCXO is followed by the buffer

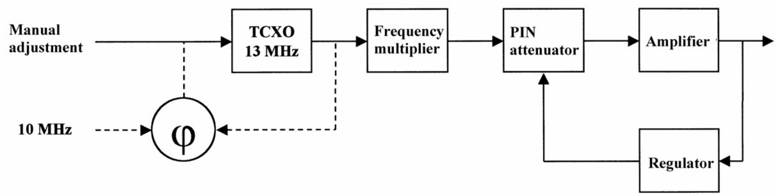

Fig 3: Block diagram showing the concept of the frequency / power standard.

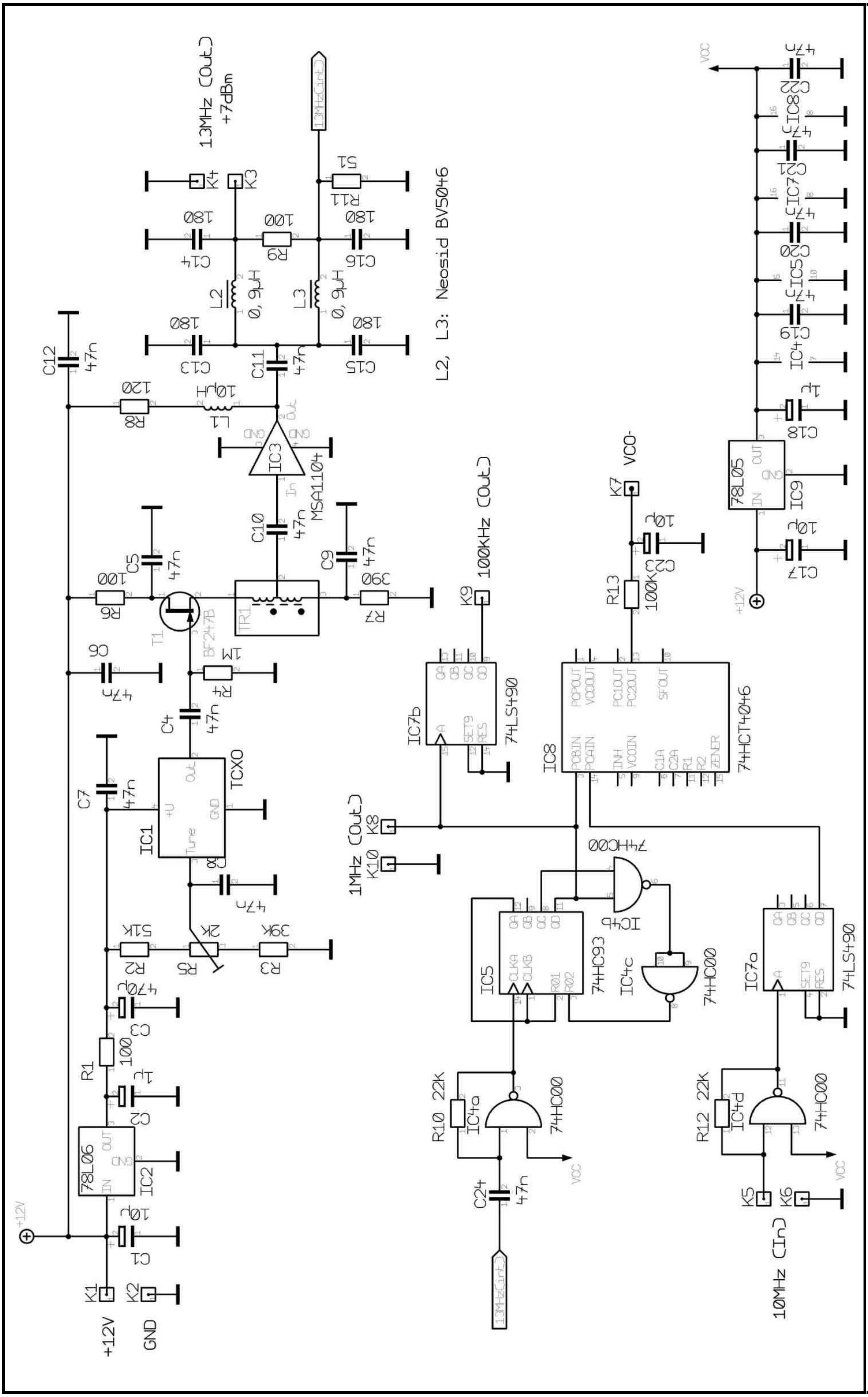

Fig 4: Circuit diagram of the TXCO for the frequency / power standard.

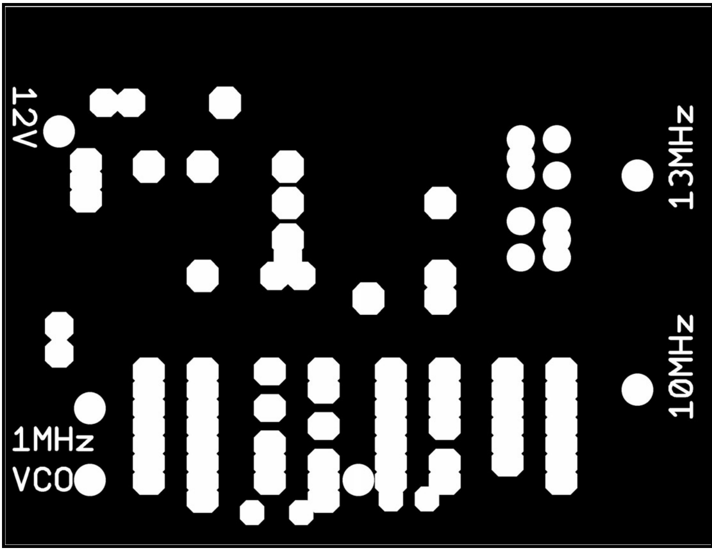

Fig 5: Top side of TXCO PCB.

stage with a type BF247B FET (T1). The latter also acts as an impedance converter to 50Ω.

The necessary amplification of approximately 13dB is provided by the MSA1104 MMIC (IC3) with an output of approximately 10mW. The latter is divided by a Wilkinson splitter (L2, L3 and C13 - C16). This gives +7dBm (5mW) at 13.0MHz available for the following stages. The power splitters second output is required internally for the PLL control circuit.

Following conversion to TTL level using IC4a (74HC00), the 13MHz is divided down to 1MHz by means of IC5 (74HC93). For any other possible uses for example as a calibration mark setter, a 100kHz signal is generated in addition through IC7b (74LS490).

The oscillator can be synchronised with a 10MHz frequency standard, as initially required. This reference signal is divided by 10 in IC7a (74LS490). Thus two 1MHz signals are available to the IC8 phase indicator (74HCT4046). The loop filter at the PLL output is designed for a high recovery time constant due to the high value TCXO in the circuit, with 100kΩ and 10µF.

3.1. Assembly instructions and putting into operation of TCXO

The TCXO is assembled on a double sided copper coated circuit board - dimensions 75mm x 100mm (Figs. 5 and 6). Due to the many connections that may be necessary, it is not intended to be built into a housing.

Following the drilling of the circuit board with a 0.8mm or 1mm. drill, the components are mounted on the board in no particular order (Figs 7 and 8). As far as possible, connections to earth (resistors, terminal pins, etc.) are soldered on both sides. This provides the necessary through plating for the earth areas.

Before the assembly is put into operation, the frequency response of the TCXO is initially recorded. All that is needed to do this is a high precision frequency counter or a frequency standard. Irrespective of whether it is synchronised using a connected frequency counter or a PLL (IC8), the tuning voltage required for the nominal frequency at the tuning input of the 13MHz TXCO is important. In the specimen assembly, this voltage required was 2.490V.

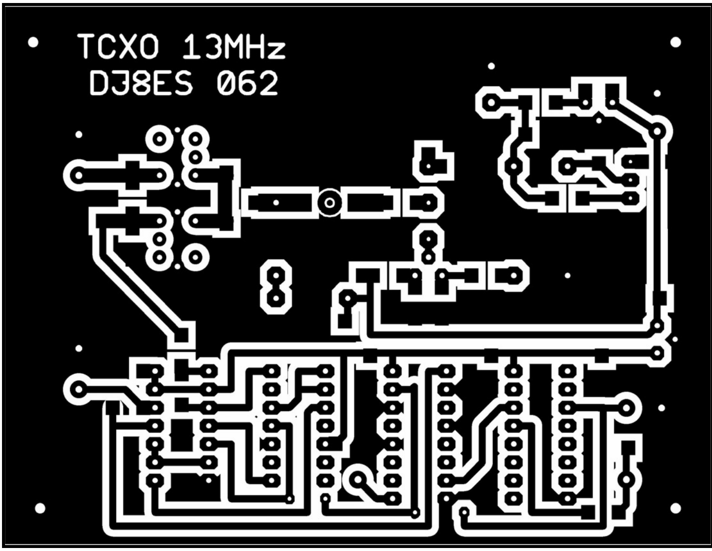

Fig 6: Bottom side of TXCO PCB.

The voltage divider made from R2 and R3 must be calculated for the tuning voltage in the next stage. This is done, following the appropriate conversion, using the formula

VTune = V * R2 / (R2 + R3)

The voltage, V is measured at the +V connection of the TCXO module. As a result of the voltage drop through R1 (100Ω), this is slightly less than the output voltage of the IC2 fixed voltage regulator (78L06). In the specimen assembly, the TCXO operating voltage was precisely 5.740V.

In the specimen assembly, the resistances are calculated at R2 = 51kΩ and R3 = 39kΩ. With a potentiometer of 2kΩ (R5), a tuning range of ±3Hz was obtained. For comparison: R5 = 1kΩ corresponds to ±1.5Hz and R5 = 5kΩ corre-

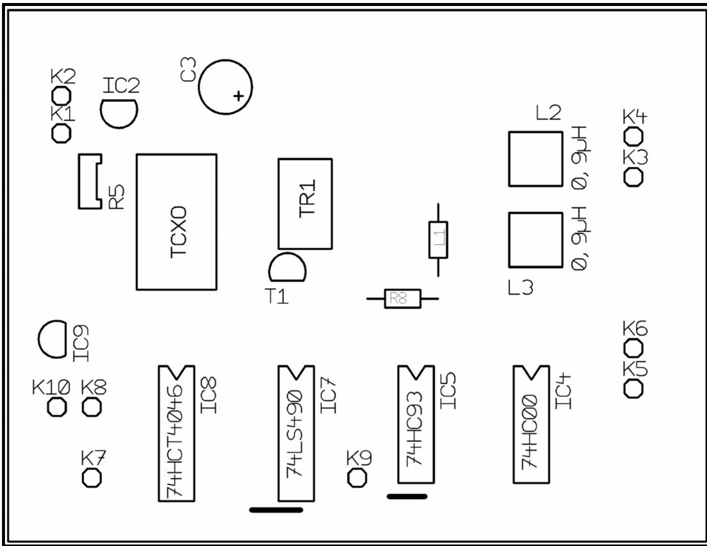

Fig 7: Component layout for the TXCO PCB showing the non SMD parts.

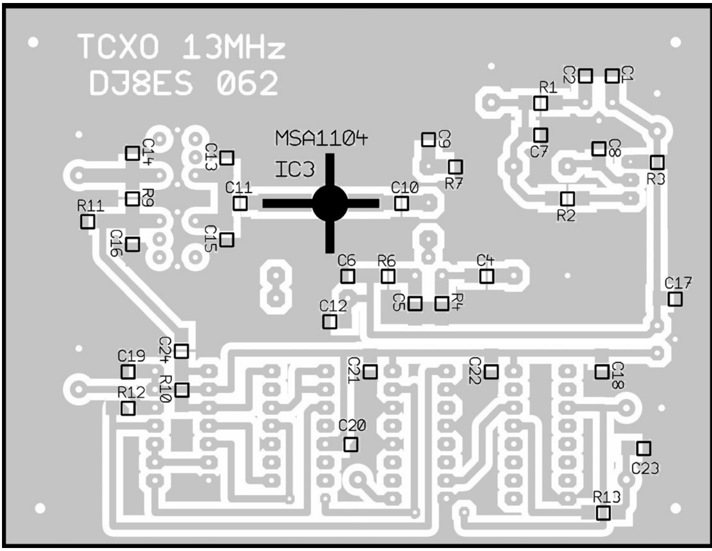

Fig 8: Component layout for the TXCO PCB showing the SMD parts.

sponds to ±7.5Hz.

Fig. 2 graphically represents the frequency response of the TCXO, plotted against the tuning voltage applied.

The tuning potentiometer (2kΩ) should be a 10 turn helical potentiometer and it should be incorporated into the front panel with the frequency tuning changeover (internal/external). The external setting can be carried out using the PLL circuit. To this end, K7 (VCO control voltage) is connected to the tuning input of the TCXO (loop from R5).

3.2. TCXO assembly components list

T1	Transistor BF247B
IC1	TCXO 13,000 MHz, Philips
IC3	MMIC MSA1104
IC4	74HC00
IC5	74HC93
IC7	74LS490
IC8	74HCT4046
IC2	78L06, 6V voltage regulator
IC9	78L05, 5V voltage regulator
L1	10 µH choke
L2, L3	BV5046 Neosid 0.9µH,
C3	470µF / 16V, electrolytic capacitor radial
C1,C17	10µF / 25V, SMD tantalum
C23	10µF / 16V, SMD tantalum
C2, C18	1µF / 16V, SMD tantalum
R5	Spindle carrier. 2kOhm, Model 64W
R8	Carbon film resistor. 120Ohm ½W, RM 10mm
TR1	Transformer (trifilar), 7 turns 0.2mm Cu enamelled wire
10 x	Terminal pin 1 mm
1 x	Circuit board DJ8ES 062

SMD components, model 1206:

14 x	47nF
4 x	180pF
1 x	5 Ohm
3 x	100Ohm
1 x	390Ohm
2 x	22kOhm
1 x	51kOhm
1 x	39kOhm
1 x	100kOhm
1 x	1MOhm

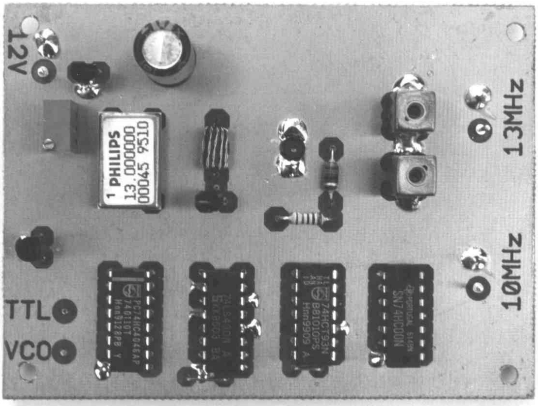

Fig 9: Completed TXCO PCB.

4. The quadrupler

One of the design considerations for the circuit was an output frequency in the area of 50MHz. To obtain this, the TCXO frequency of 13.0MHz must be quadrupled. This achieved with the transistor T1 (BFR90a). It has a high resistance input using of a 1:9 transformer (TR1). Approximately 7 turns (trifilar) are wound on a ferrite core and wired up for the transformer. The type and form of this ferrite core are not at all critical.

A 6dB attenuator is connected in series to match the level of this quadrupler stage to the output of the TCXO assembly.

The 3 stage band filter following the transistor filters out the desired 52.0MHz. Fig. 23 shows the frequency spectrum, measured at full power at the output of the amplifier stage described below (Section 5). All harmonic and spurious signals are attenuated by more than 35dB.

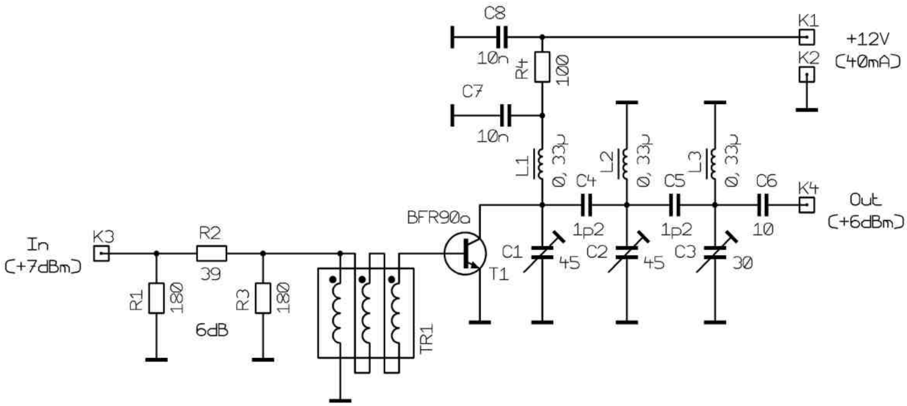

Fig 10: Circuit diagram of quadrupler with three stage band pass filter.

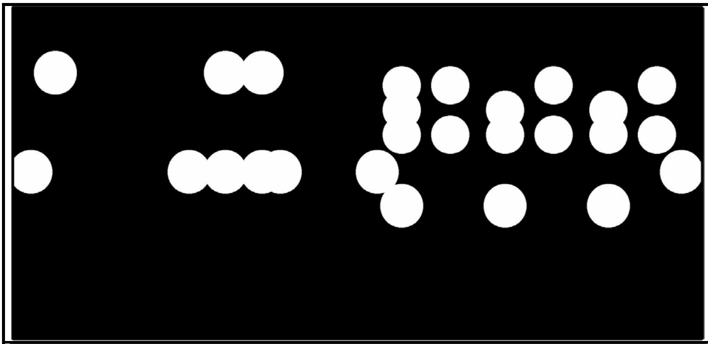

Fig 11: Top side of quadrupler PCB.

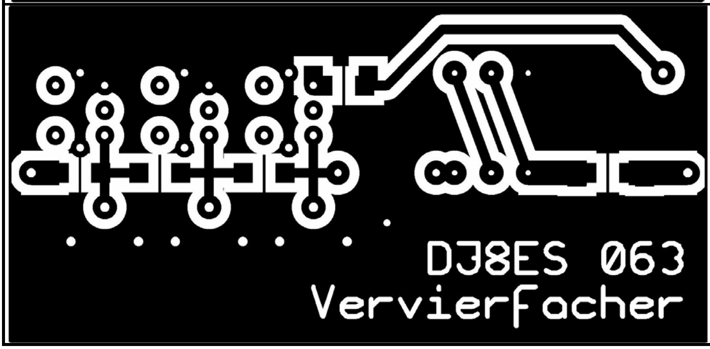

Fig 12: Bottom side of quadrupler PCB.

4.1 Assembly instructions and putting the quadrupler into operation

The quadrupler assembly is mounted on a double sided copper coated circuit board, which has the dimensions 34mm x 72mm (Figs. 11 and 12). It thus fits into a standard 37mm x 74mm x 30mm tinplate housing. In the specimen assembly, the input and output are SMA sockets. The operating voltage (+12V at 40mA) is fed in through a 1nF feedthrough capacitor.

When the circuit board has been drilled, it is populated in accordance with Figs 13 and 14. Special attention should be paid to the 1:9 transformer, do not to mix up the two connecting wires!

It makes sense to solder the circuit board into the tinplate housing before mounting the components. The circuit board is inserted deep into the housing. The earth areas are soldered to the frame on both sides. Both the input and output and the

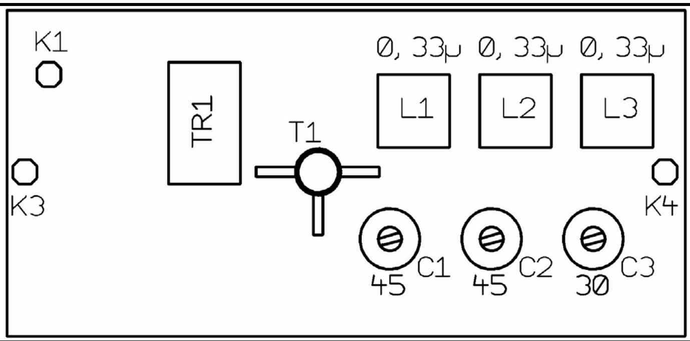

Fig 13: Component layout of quadrupler PCB showing non SMD parts.

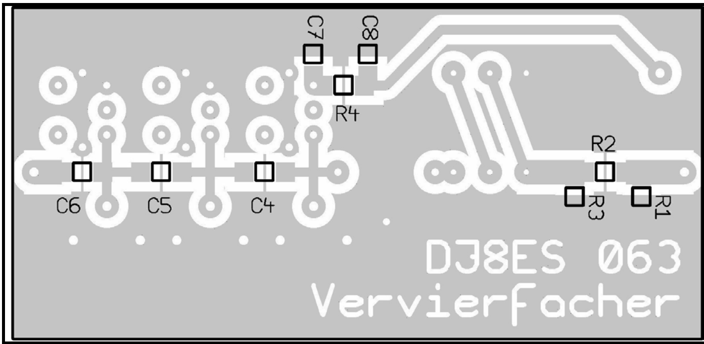

Fig 14: Component layout of quadrupler PCB showing SMD parts.

power supply are connected to the circuit board using thin connecting wires.

The assembly can be put into operation immediately after a visual check. The foil trimmers in the 3 stage band filter are pre-adjusted to the mean setting.

With an input of +7dBm (5mW) from the TCXO assembly and a calibrated band pass filter, the quadrupler should supply a frequency of 52MHz at the output socket, with a level of approximately +6dBm (4mW)

4.2. Quadrupler components list

T1	BFR90a
L1-L3	BV5049 Neosid 0.33µH
TR1	Transformer (trifilar), 7 turns with 0.2mm Cu enamelled wire
C1, C	45pF (violet), foil trimmer RM 7.5
C3	30pF (red), foil trimmer RM 7.5
1	Circuit board DJ8ES 063

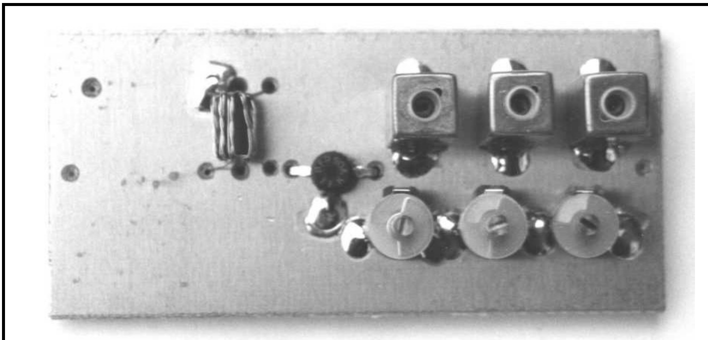

Fig 15: Top side of completed quadrupler PCB.

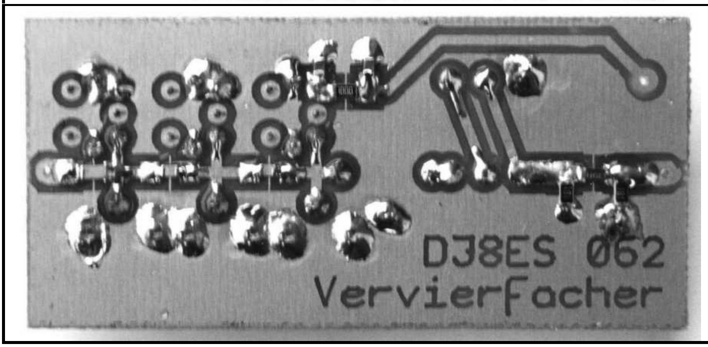

Fig 16: Bottom side of completed quadrupler PCB.

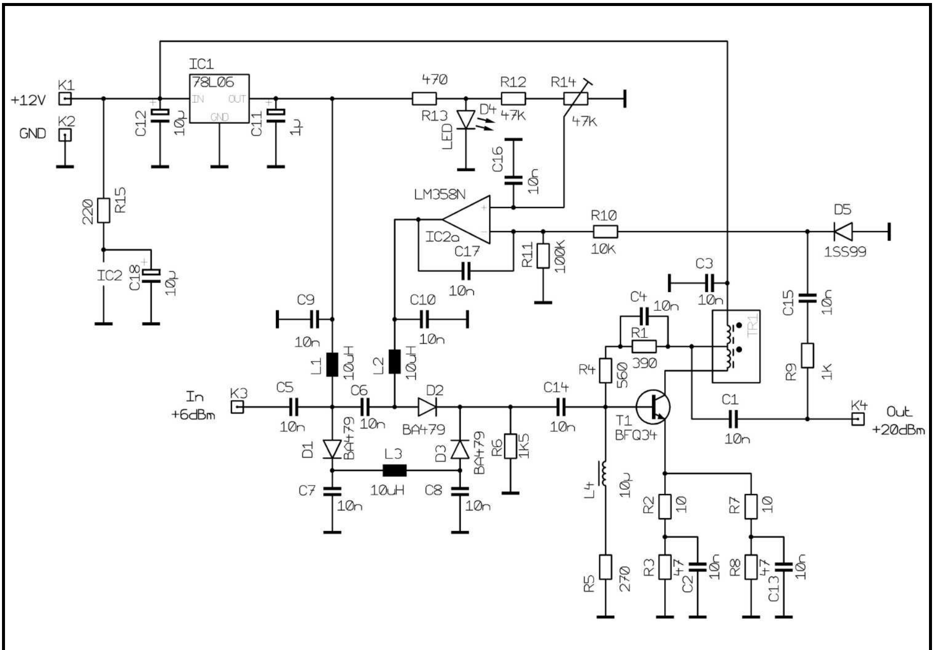

Fig 17: Circuit diagram of amplifier.

1 x	37 x 74 x 30 tinplate housing
2 x	SMA flanged bush
1 x	1nF, feedthrough capacitor

SMD components, model 1206:

C4,C5	1.2pF
C6	10pF
C7,C8	10nF
R2	39Ohms
R4	100Ohms
R1,R3	180Ohm

5. The amplifier assembly

The amplifier is assembled using the tried and tested 50Ω broadband technology (Fig.17). The transistor T1 (BFQ34) can adequately handle the output of +20dBm (100mW) plus a few dB in reserve. The stage supplies approximately 17dB of amplification.

Naturally, a cheaper type can be used in the circuit. However, it must also be able to produce the desired output!

A PIN diode attenuator is connected in front of the amplifier. The circuit, which has 3 BA479 diodes (D1 - D3) is taken from an old Siemens application. Attenuation is adjusted using the diode current.

A small part of the output is rectified, using a 1SS99 Schottky diode. The DC voltage obtained is compared in the operational amplifier, IC2a (LM358N) with the reference set using the trimmer, R14 (47kΩ). The output controls the PIN diode attenuator.

The interesting design for stabilising the reference voltage using a light emitting diode (D4) comes from Bernd Kaa (DG4RBF) [2].

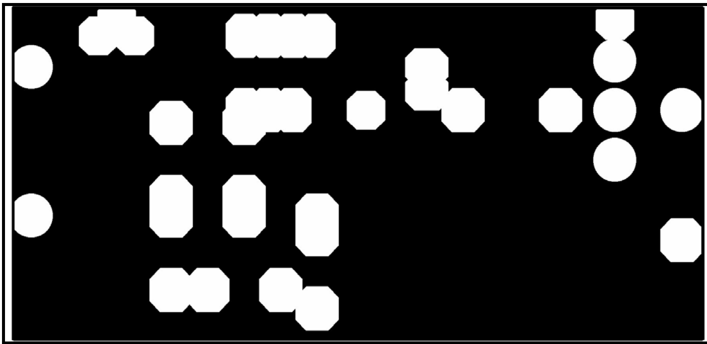

Fig 18: Top side of amplifier PCB.

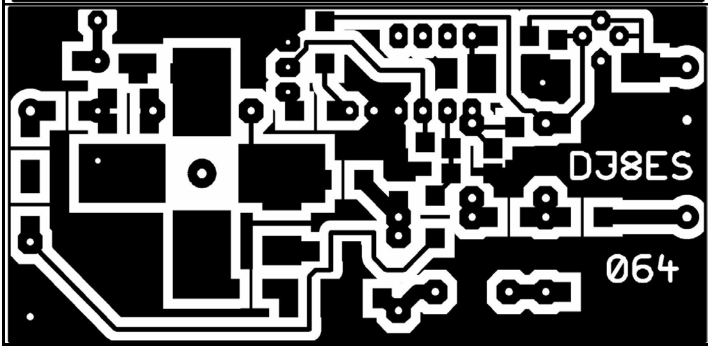

Fig 19: Bottom side of amplifier PCB.

5.1. Assembly instructions and putting the amplifier into operation

The amplifier assembly is mounted on a double sided copper coated circuit board, which has the dimensions 34mm x 72mm (Figs. 18 and 19). It fits into a standard tinplate housing with the dimensions 37mm x 74mm x 30mm. In the specimen assembly, SMA sockets have been used for the input and output. The operational voltage of +12V (approximately 90mA) is fed in through a 1nF feedthrough capacitor.

The fully drilled circuit board is inserted deep into the housing and the earth areas are soldered to the housing frame all round on both sides. The circuit board is populated in accordance with the component plans in Figs 20 and 21 in no particular order.

The amplifier is designed to be for broadband. There is thus no need for calibration, as there normally would be.

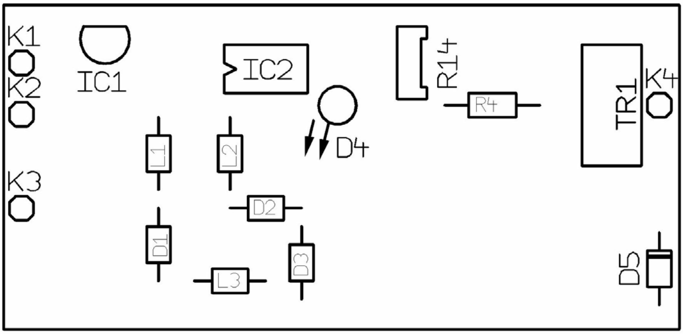

Fig 20: Component layout of amplifier showing non SMD parts.

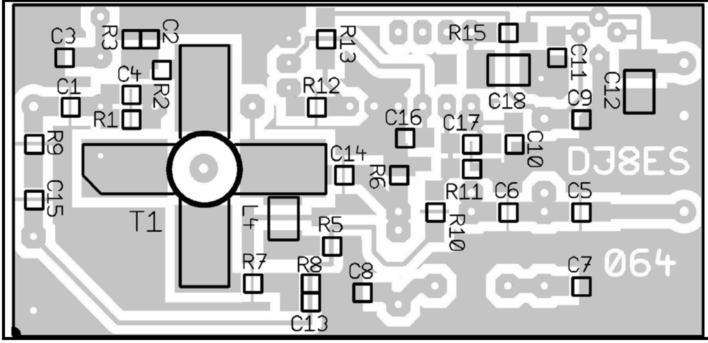

Fig 21: Component layout of amplifier showing SMD parts.

The 47kΩ trimmer is used to set the output at 100mW. The quadrupler described above is used for input.

5.2. Amplifier assembly components list

IC1	78L06, Voltage regulator
IC2	LM358N, Operational amplifier
T1	BFQ34
D1-D3	BA479, PIN diode
D4	LED
D5	1SS99, Detector diode
L1-L3	10µH, Choke axial, RM 7.5 mm
L4	10µH, SMD choke
C11	1µF / 16V, SMD tantalum electrolytic capacitor
C12	10µF / 16V, SMD tantalum electrolytic capacitor
R4	560Ohm, RM 10mm
TR1	Transformer (bifilar), 7 turns 0.2mm Cu enamelled wire
1 x	Circuit board DJ8ES 064
1 x	Tinplate housing 37 x 74 x 30 (mm)
2 x	SMA flanged socket
1 x	Feedthrough capacitor 1nF, solderable

SMD components, models 1206:

16 x	10nF
2 x	10Ohm
2 x	47Ohm
1 x	220Ohm
1 x	270Ohm
1	390Ohm
1 x	470Ohm
1 x	1kOhm
1 x	1.5kOhm
1 x	10kOhm
2 x	47kOhm
1 x	100kOhm

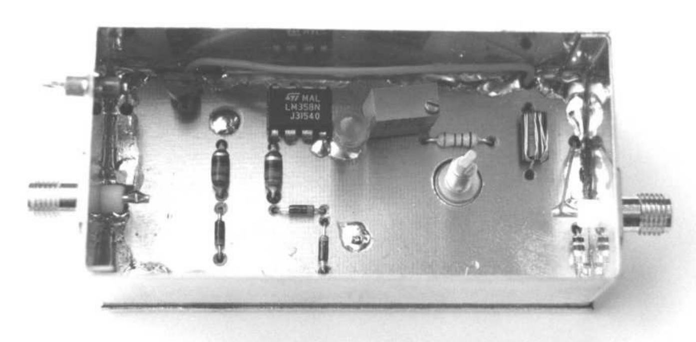

Fig 22: Completed amplifier PCB in it's tinplate housing.

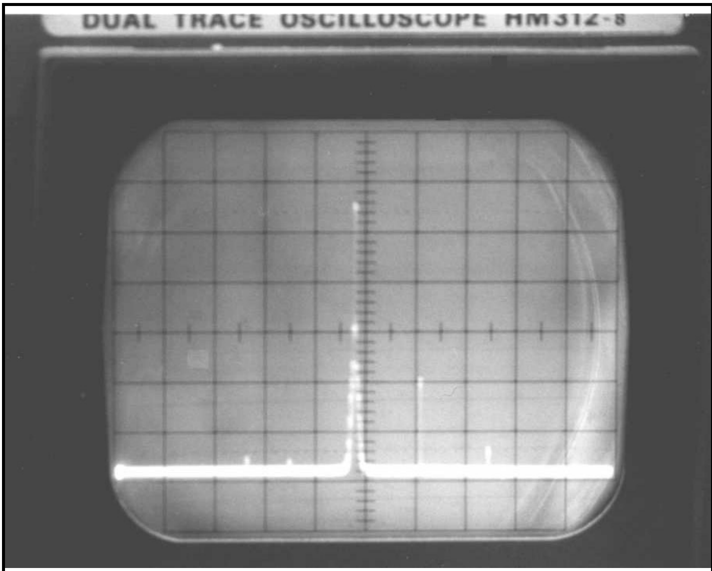

Fig 23: Picture of the output spectrum showing that any unwanted signals are at least 35dB below the wanted signal.

6. Summary

The frequency / power standard described offers a favourably priced and yet high quality aid for calibrating simple frequency counters and diode detectors or bolometer heads for power measurement.

The modular construction, broken down into oscillator, frequency multiplier and regulated power amplifier, makes individual tuning processes possible while keeping within the overall concept initially discussed. Thus a modification to another frequency range and/or another output level is possible.

As an option, a switchable attenuator, like, for example, the one mentioned in [1], can be added at the output. The output level can thus be adjusted in 1dB steps from +20dBm to 107dBm. That is more than adequate for calibration purposes.

7. Literature references

[1] Wolfgang Schneider, DJ8ES: Control logic for a switchable attenuator; VHF Communications 1/03, Pp. 8 - 13

[2] Bernd Kaa, DG4RBF: KW-Synthesizer from 1 - 65 MHz with DDS and wobble function;
UKW Berichte 4/99, Pp. 205 - 222